Using GIS to Evaluate Sediment Contamination in Estuarine Habitats of the Duwamish River

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Abstract

The degree to which environmental contamination impacts natural resources is a function of many variables. In addition to the concentration and toxicity of a contaminant in the environment, several other factors affect organism exposure and uptake. An examination of the distribution of habitat types in a study area can provide information pertinent to the analysis of the effects of contaminants on ecological receptors of concern to resource managers.

In areas where several habitat types occur over a relatively small area, and many different hazardous substances have been released and are distributed in a heterogeneous fashion, the analysis of the absolute and relative impacts of these substances is complex. A GIS project has been developed to aid in the analysis of impacts to natural resources in the Duwamish River from past and current releases of hazardous substances. A base map was created from aerial photography taken during a low tide event in July of 1999. Habitats were delineated using functional categories developed collectively by the Elliott Bay & Duwamish Natural Resource Trustees in 2000. A database was created to compile sediment chemistry results from over 1,000 sampling stations from more than a dozen sampling events undertaken by various parties over the last decade.

The GIS project and associated database allow the user to analyze the distribution of one or several contaminants, relative to different habitat types of varying productivity and resource utilization.

Introduction

The Lower Duwamish River in Seattle, Washington, has undergone dramatic physical changes from its pre-industrial state. Alterations to the course of the river since the turn of the 20th Century are illustrated in Figure 1. One result of these changes has been the loss of habitats important to migrating salmonids and other natural resources.

[Editor’s note: Figures appear at the end of this paper, following the References section.\

Urbanization, commercial development and industrial operations in the Duwamish corridor, have resulted in releases of hazardous substances to the river. The extent to which these releases have impaired the aquatic ecology of the Duwamish is the subject of continuing environmental investigation, cleanup, and restoration efforts.

Purpose

Environmental contamination impacts ecological receptors in several ways. These variables include a chemical's concentration, its toxicity to specific receptors, and its bioavailability. This poster illustrates the use of a Geographic Information System (GIS) to examine the relative distribution of habitat types and contaminant concentrations in a study area. Analysis of the distribution of contaminants in relation to habitats helps us evaluate the potential for exposure, uptake, and effects to aquatic organisms.

Methods

Aerial photographs were taken during a low-tide event on July 13, 1999 over approximately7 river miles, from Elliott Bay to a point upstream of Turning Basin No. 3, the head of navigation. These photographs were converted to electronic files and spatially combined to create an up-to-date, accurate, and highly detailed basemap for use in an ArcView (version 3.1) desktop GIS. The GIS combines numerous types of geo-referenced data so that the user can visualize the data in the correct spatial relationship, at a variety of scales. NOAA's Duwamish Estuary ArcView project is projected in Washington State Plane, North, NAD 83, with distances measured in feet.

The Elliott Bay and Duwamish River Natural Resource Trustees defined six broad habitat classifications for resource analysis (Table 1). Habitat types were visually delineated within the GIS from the geo-rectified aerial photographs to create habitat GIS themes showing the type, extent, and location of each habitat area (Figure 3). These habitat delineations were ground-truthed by viewing the shoreline from a small watercraft on a subsequent negative tide, and modifications incorporated into the ArcView project. Shallow and deep subtidal habitats were defined from sounding data collected by the U.S. Army Corps of Engineers, using the most recent available data.

Table 1: Habitat Types Delineated in the Project:

Marsh: Shoreline areas containing wetland vegetation. The upper elevation limit is defined by the extent of hydrophytic vegetation, generally between Mean Higher High Water and Extreme High Water (+11.9 to +13.5 ft MLLW). The lower limit of vegetation is approximately Mean High Water (+10.2 MLLW).
Mudflat: Unvegetated intertidal areas characterized by sandy, silty, or muddy substrates. The approximate lower elevation limit is -2.0 MLLW, the approximate conditions present at the time the aerial photos were taken.
Riprap: Steep intertidal shoreline characterized by debris and/or boulders.
Vegetated Buffer: Vegetated areas located upland of, and contiguous with, intertidal habitats; and where the vegetation is dominated by native shrub/scrub and woody species. These areas provide wildlife refuge, insect production beneficial to aquatic organisms, and protection from human encroachment.
Shallow Subtidal: Continuously submerged areas ranging in elevation from the mean lower low water mark to a depth of 14 ft.
Deep Subtidal: All areas where the water depth is greater than 14 ft.

Data were compiled from 12 reports since 1990 documenting investigations of sediment contamination in the lower Duwamish River (Table 2). Reported contaminant concentrations and physical characteristics were combined in a relational database in a specific format that is compatible with Query Manager (QM), a utility developed by NOAA's Coastal Protection and Restoration Division. QM is a nested menu of questions that can be used with a database in compatible format to sort, select, and analyze large data sets. QM allows the user to select all the data for a particular contaminant (e.g., mercury), or group of contaminants (e.g., PCBs) from the combined dataset or a subset of selected studies. These data are imported to the ArcView project in a spreadsheet that includes the name of the source study, the date of sample collection, the contaminant concentration, any qualifier that the analytical laboratory included with the analysis (e.g., below detection), and the coordinates of the sample station (Table 3). For example, in Figure 2, the results of a query for total PCB concentration in surface sediment in all samples recorded in the database were imported to the ArcView project for display in relation to a geographic characteristic, the shoreline.

Table 2: Sources of sediment chemistry data included in the project database as of November 1, 2000.

King County, WA, 1997. Duwamish River Water Quality Assessment. Data from SEDQUAL-February 1999.
NOAA, 1998. The Duwamish Waterway Characterization Data Report. National Marine Fisheries Service, Seattle, WA.
EVS Environmental Services, 1995. Harbor Island Supplemental Remedial Investigation. Data from SEDQUAL-February 1999.
Roy F. Weston, Inc., for the Boeing Company, 1994. Comprehensive RCRA Facility Investigation Report, Boeing Plant 2, Phase 1A. Electronic data files provided to NOAA Office of Response and Restoration.
Roy F. Weston for EPA Region 10, Seattle, WA 1994. Harbor Island Remedial Investigation. Data collected in 1991. Electronic data files provided to NOAA Office of Response and Restoration.
Roy F. Weston for the Boeing Company, 1995. Comprehensive RCRA Facility Investigation Report, Boeing Plant 2, Phase 2A. Electronic data files provided to NOAA Office of Response and Restoration.
Roy F. Weston, Inc. for the Boeing Company, 1996. Comprehensive RCRA Facility Investigation Report, Boeing Plant 2, Phase 2B. Electronic data files provided to NOAA Office of Response and Restoration.
Roy F. Weston, Inc., for US EPA Region 10, Seattle, WA 1998. Site Inspection Report for the Lower Duwamish River (RK 2.5 to 11.5) Seattle, WA, Vols. 1 & 2. Office of Puget Sound, Seattle, WA.
Unknown, 1996. Crowley Marine Services, DY96. Data from SEDQUAL-February 1999.
Unknown, 1997. Port of Seattle, Terminal 5, DY97. Data from SEDQUAL-February 1999.
Unpublished, 1997. Boeing Duwamish Waterway-Phase 1 Data. Electronic data files provided to NOAA Office of Response and Restoration by the Boeing Company.
U. S. Army Corps of Engineers, 1997. USACE Duwamish O&M, DY97. Data from SEDQUAL-February 1999.

Table 3: An example of Query Manager output, for import into ArcView. The fields shown are (from left to right): Study identifier, Station identifier, Sampling date, Study name, Lower extent of sample, Contaminant measured, Concentration, Laboratory qualifier, Unit of measure, Percent organic carbon, Latitude and Longitude. Total PCB concentrations are computed by QM from congener and Aroclor data to maximize comparability of the different datasets. Below detection limit-qualified values (i.e. "U") are equated to a concentration of 00.0, unless all values at a station are below detection-qualified, in which case, the maximum single detection limit is reported, with a "U" qualifier.

Study identifier	Station identifier	Sampling date	Study name	Lower extent of sample	Contaminant measured	Concen-tration	Lab. qualifier	Unit of measure	Percent organic carbon	Latitude	Longitude
B3	EIT087	19970918	1998 NMFS Duwamish Waterway Charactize	10.00 (cm)	PCB_SUM	5.60000		PPB	0.35	47.56098333	-122.34475000
B3	EST108	19971014	1998 NMFS Duwamish Waterway Charactize	10.00 (cm)	PCB_SUM	5.60000		PPB	0.25	47.51090000	-122.29653333
B3	EST114	19970930	1998 NMFS Duwamish Waterway Charactize	10.00 (cm)	PCB_SUM	5.70000		PPB	0.39	47.51265000	-122.30221667
B4	N-14	19911010	1991 EPA Harbor Island RI	2.00 (cm)	PCB_SUM	5.90000		PPB	0.90	47.58817900	-122.35342400
B4	W-02	19911011	1991 EPA Harbor Island RI	2.00 (cm)	PCB_SUM	5.90000	U	PPB	0.23	47.57243800	-122.35520300
55	DR239	19980827	1998 EPA Lower Duwamish River	10.00 (cm)	PCB_SUM	6.00000		PPB	1.69	47.51952000	-122.30563000
B3	EST113	19970930	1998 NMFS Duwamish Waterway Charactize	10.00 (cm)	PCB_SUM	6.00000		PPB	0.13	47.51295000	-122.30300000
B3	WIT294	19970916	1998 NMFS Duwamish Waterway Charactize	10.00 (cm)	PCB_SUM	6.00000		PPB	1.13	47.55896667	-122.34715000
B3	WIT254	19971017	1998 NMFS Duwamish Waterway Charactize	10.00 (cm)	PCB_SUM	6.10000		PPB	1.92	47.51171667	-122.29973333
B4	W-05	19911011	1991 EPA Harbor Island RI	2.00 (cm)	PCB_SUM	6.30000	U	PPB	0.21	47.57378700	-122.35696400
55	DR067	19980818	1998 EPA Lower Duwamish River	10.00 (cm)	PCB_SUM	7.00000		PPB	0.82	47.56535000	-122.34887000
55	DR100	19980820	1998 EPA Lower Duwamish River	10.00 (cm)	PCB_SUM	7.00000		PPB	0.61	47.54548000	-122.33644000
55	DR161	19980831	1998 EPA Lower Duwamish River	10.00 (cm)	PCB_SUM	7.00000		PPB	2.87	47.54839000	-122.33931000

Results

The aerial photographs show that the Duwamish estuary has become a highly developed area. Nonetheless, populations of wild and hatchery-reared salmon continue to use the Duwamish estuary during migration to and from freshwater spawning areas and hatcheries. An estimated 11 million juvenile chinook salmon migrate each year out of the Green River-Duwamish River system through the Duwamish estuary. Approximately 25% of these juveniles are believed to be wild salmon, with the remaining 75% from hatcheries (Varanasi et al 1993).

Over the past several years, the Environmental Conservation Division of NOAA's National Marine Fisheries Service has sampled juvenile salmon at Kellogg Island and Slip 4 in the Duwamish, as well as at upstream reference sites (including hatcheries). Fish tissues have been analyzed to determine the amount of PCBs present in fish collected from these sites, and to evaluate the amounts of PCBs accumulated during their migration through the Duwamish system.

Meador (2000) used these results, along with data on PCB contamination in Duwamish River surface sediments, to evaluate the relationship between concentrations of PCBs in sediment and fish tissue. He then used literature describing physiological responses in salmonids exposed to PCBs to derive a Sediment Effect Threshold (SET) specific to the Duwamish. Using two sets of assumptions, Meador calculated two sediment PCB concentrations in the Duwamish estuary (225 and 113 ug/kg, or parts per billion, dry weight) associated with adverse effects to juvenile salmon. Figure 2 illustrates where concentrations of PCBs in this range and higher occur in surface sediment in the lower Duwamish river.

In Figure 2, the concentration distribution of a single type of contaminant (PCBs) is displayed in relation to the River shoreline. However, additional contaminants are found in surface sediment of the Duwamish, and the potential effects from these contaminants need evaluation also. The QM utility simplifies retrieval of concentration data for each contaminant from the database, which then can be displayed on the maps and aerial photographs that are in the ArcView project. QM also includes the ability to compare a contaminant concentration to a “benchmark” concentration that is an estimator of probable toxicity for that contaminant. One of these benchmarks is the Effects Range-Median, the concentration of a contaminant at which significant adverse effects to benthic fauna were identified in 50% of evaluated field and laboratory studies from around the country (Long and others 1995). To estimate the overall (i.e., from all contaminants) potential for adverse effects in a sample, we create a ratio of each contaminant concentration in relation to its ERM, and then map the maximum ratio at each station. This allows us to use all the available data to estimate the potential for toxicity at each station, even though the stations are from different studies and may have reported a different number, or list, of chemicals. Figure 3 shows the maximum ERM ratio from the concentration data at each station, in relation to the aerial photograph and delineated habitats for a small portion of the estuary near Slip 4. This type of display helps us to determine the overall potential for toxicity in relation to habitats used by salmonids, and other aquatic organisms, for feeding and refuge.

Conclusions

Spatial analysis of combined GIS themes containing habitat and contaminant information helps users compare the relative extent and distribution of sediment contamination in relation to habitats, enhancing the analysis of potential ecological exposures to hazardous substances.

The Elliott Bay/Duwamish Natural Resource Trustees are continuing to expand and refine the Duwamish database and GIS project illustrated in this poster.

Further studies focused on species of special concern are warranted to strengthen current understanding of habitat utilization in the Duwamish and similar systems throughout Puget Sound. Additional studies also are needed to strengthen current understanding of uptake, bioaccumulation, and ecotoxicological effects of contaminants commonly found in the Duwamish and other urban estuaries of Puget Sound.

References

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Varanasi, U., E. Casillas, M.R. Arkoosh, T. Hom, D.A. Misitano, D.W. Brown, S-L Chan, T.K. Collier, B.B. McCain, and J.E. Stein. 1993. Contaminant exposure and associated biological effects in juvenile chinook salmon (*Oncorhynchus tshawytscha*) from urban and nonurban estuaries of Puget Sound. NOAA Technical Memorandum NMFS-NWFSC-8. Seattle: National Marine Fisheries Service, National Oceanic and Atmospheric Administration.

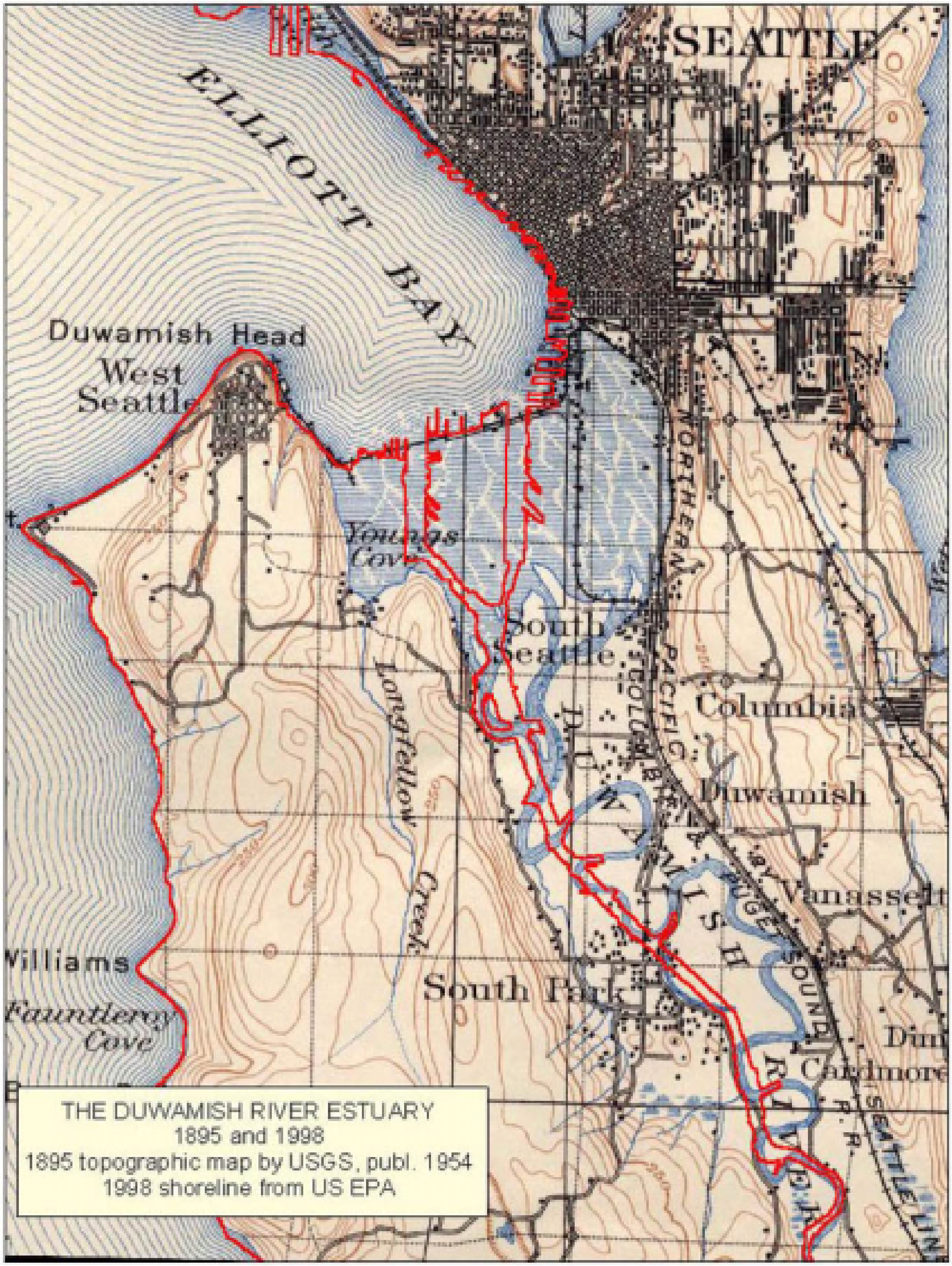

Figure 1. Alterations to the course of the Lower Duwamish River in Seattle, Washington, since the turn of the 20th Century.

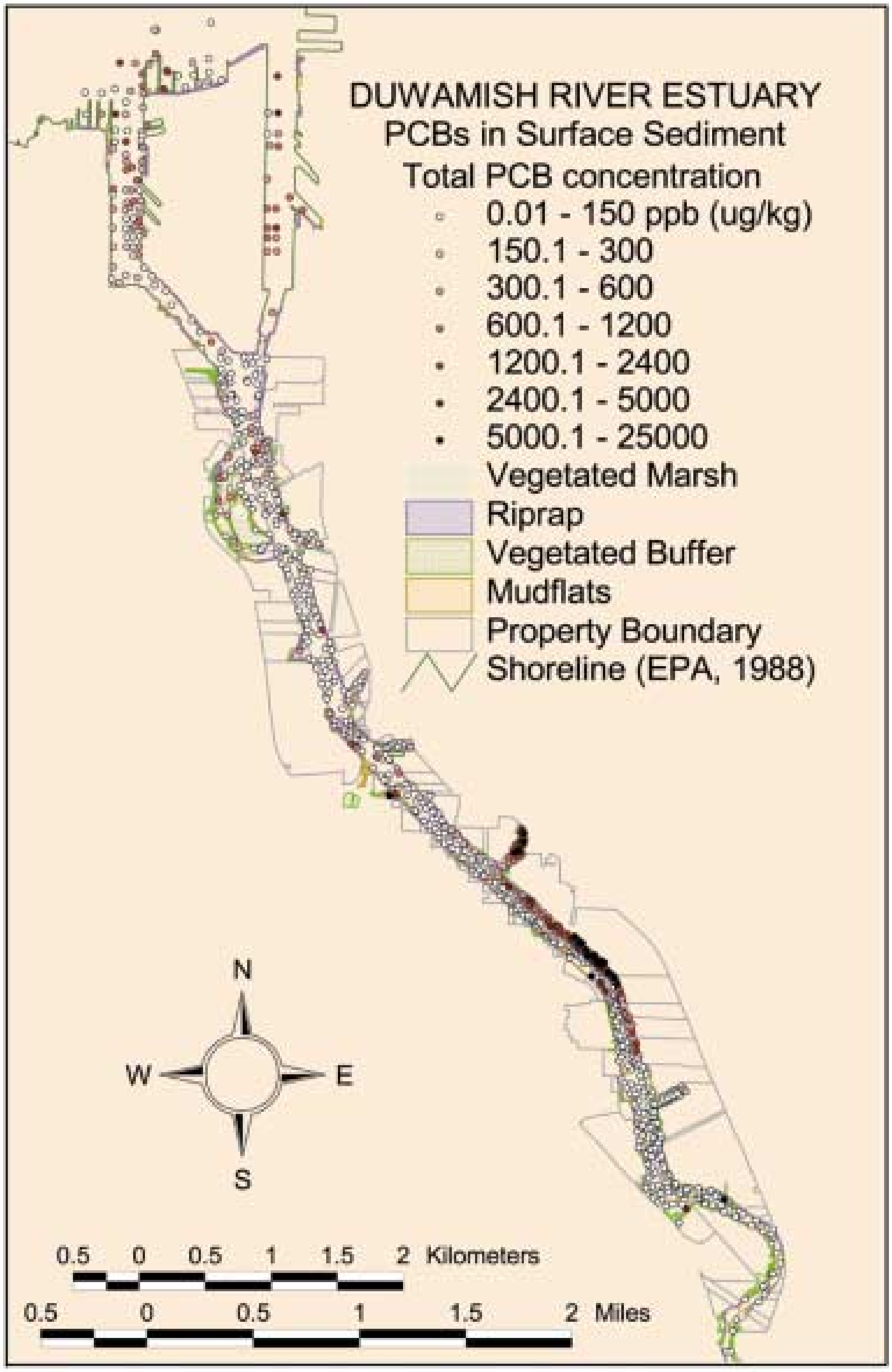

Figure 2. The results of a query for total PCB concentration in surface sediment in all samples recorded in the database were imported to the ArcView project for display in relation to a geographic characteristic, the shoreline.

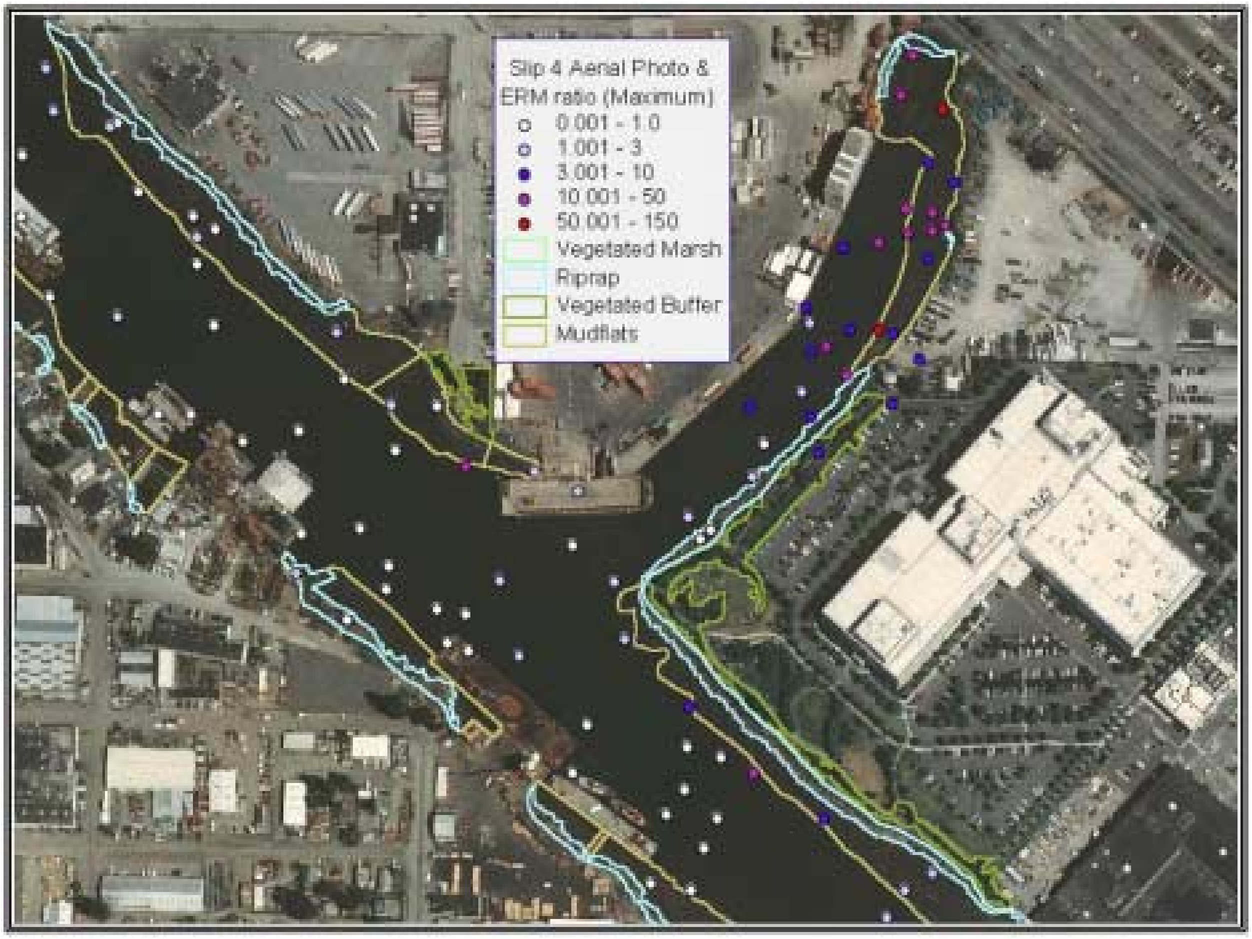

Figure 3. The maximum ERM ratio from the concentration data at each station, in relation to the aerial photograph and delineated habitats for a small portion of the estuary near Slip 4.